NASA TECHNICAL TRANSLATION NASA TT F-15,227

X-RAY KYMOGRAPHIC INVESTIGATIONS OF THE CENTRAL CIRCULATORY ORGANS IN THERAPEUTIC BATHS AND IN HYDROSTATIC PRESSURE ELEVATION. THEIR TECHNOLOGY, RESULTS AND POTENTIAL DEVELOPMENTS

A review

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(NASA-TT-F-15227) X-RAY KYMOGRAPHIC INVESTIGATIONS OF THE CENTRAL CIRCULATORY ORGANS IN THERAPEUTIC BATHS AND IN HYDROSTATIC (Scientific Translation Service) 36 p HC $4.00 CSCL 06P G3/04 N74-13777 Unclas 25363

Translation of: "Röntgenkymographische Untersuchungen der zentralen Kreislauforgane während therapeutischer Bäder und bei hydrostatischer Druckerhöhung. Ihre Technik, Ergebnisse und Entwicklungsmöglichkeiten", Archiv. für Physikalische Therapie, Vol. 8, 1956, pp. 66-82.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 JANUARY 1974

X-RAY KYMOGRAPHIC INVESTIGATIONS OF THE CENTRAL CIRCULATORY ORGANS IN THERAPEUTIC BATHS AND IN HYDROSTATIC PRESSURE ELEVATION. THEIR TECHNOLOGY, RESULTS AND POTENTIAL DEVELOPMENTS

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The work of Hauffe mentioned a roentgenologically detectable reduction in the heart shadow on the fluoroscope screen in the Hauffe rising arm baths. It was on study of this work that it occurred to the author of this work, at the beginning of the third decade, to have these reports tested with the more exact methods available to him as the chief physician of the former Rieder Institute. At the same time, Hauffe's statements, which could not be established by X-ray, on the more opposing action of the full bath on the central circulatory organisms were to be subjected to testing by X-ray. / 66*

There were no problems in such investigations with the Hauffe rising partial baths. In addition, the X-ray kymography of the heart by Stumpf's method, developed at the Institute, and the X-ray kymographic apparatus provided by Stumpf could be used. It was possible to confirm the fundamentals of Hauffe's reports (Epple).

The solution of the second problem was considerably less simple. This was the X-ray checking on the behavior of the heart size in full baths. In 1934 the experts were still denying the feasibility of such a study. The fact that a person as

* Numbers in margin indicate pagination in original foreign text.

experienced in X-ray technology as Groedel, who had provided the apparatus for direct X-ray cinematography and was simultaneously very interested in balneology, and had devoted a section in his X-ray text to the discussed heart expansion in full baths, had not mentioned any X-ray method for this, was at first not encouraging. But we had already, in 1932, introduced 4 mm of aluminum / 67
for stomach fluoroscopy in general for patient protection. This is a technical modification which goes back W. Frik, Sr., 1926. Therefore we knew that, contrary to all expectation, the additional interposition of 4 mm aluminum scarcely affected X-ray pictures with higher voltages. Thus, we had the back of a bathtub made of zinc plate replaced with 2 mm of aluminum, and used the remaining 2 mm layer of aluminum for other installations which will be shown later. In the course of development of this equipment, the author and his coworkers, in long years of work, were able to make satisfactory X-ray pictures of the heart, even in any therapeutic full bath. In 1939, finally, along with Willbold, they were able to build X-ray cinematography into the investigative system. This, to be sure, was an advance that could no longer be used because the entire apparatus was destroyed in the war. The author and his coworkers have steadily approached various questions of circulatory action in full baths. This will be shown in the following. Now that the development of X-ray technology in recent years has considerably simplified and improved the applicability of the method through providing rotating-anode tubes with very high voltage resistance, they wish to disclose this method, which has been published only in part, to wider circles in summary. This is even more the case because systematic research on hydrostatic effects, in the positive and negative senses is no doubt also a practically important object of balneotherapeutic research. In the current state of X-ray technology, such work could also be done at the research institutes of the healing baths for circulatory diseases. This could give a new direction of work

which could also be of interest in other provinces. For instance, this subject could yield many relations for circulatory physiology, roentgenology, experimental pharmacology, etc.

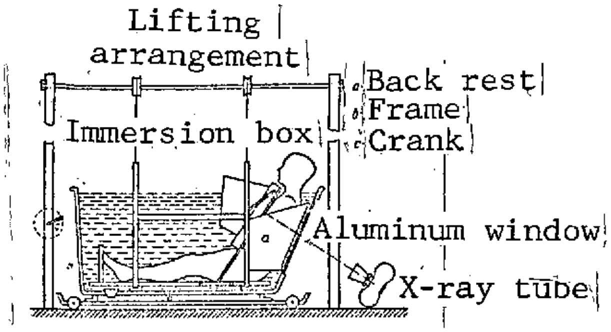
The preceding discussions are intentionally limited to the effects of hydrostatic pressure on the central circulatory organs which can be determined by X-ray. Mr. Stigler reports at the same place on the problems explained physiologically and the previous development of the applicable views, which were exposed to many erroneous developments. Mr. Stigler deserves the reward of having been occupied experimentally in this field for many years since 1911.

1. Equipment for balneologic-X-ray kymographic and X-ray cinematographic studies

After our own experiments with primitive wooden immersion cassettes in 1935, we began to develop the large balneokymographic full bath equipment with its additional installations for investigation in CO_2 baths and in mud baths, consisting of the special tub with an aluminum back wall, the aluminum immersion cassettes for the kymograph and fluoroscope screen, the pulley equipment, and various auxiliary devices (Figure 1 a-c).

So that we could follow the heart action and heart size roentgenologically and roentgen-kymographically in the ordinary or the therapeutic full baths, there were five initial requirements to be met: /68

1. It was necessary that the picture could be made through the back wall of the bath. This was made possible simply by using an aluminum window 1.0 - 2.0 mm thick. But here it was necessary to consider various angles of tilt for this back wall, as the



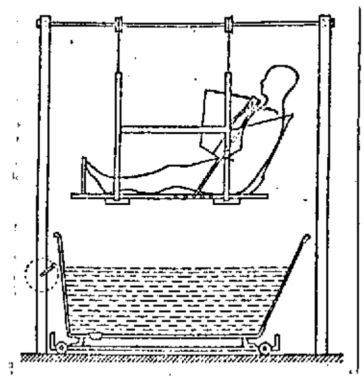


Figure 1a

Figure 1b

Figure 1a. The equipment in position for recording a kymogram, showing the immersion cassette for the kymograph, the lifting frame for the patients, the aluminum window at the back of the tub, and the tub carriage. The first design in the photo of Ekert, Balneology 5(1938).

Figure 1b. The equipment during change of the bath medium. Provisions for fixing the patient ensure that the same position is maintained when the patient is cranked up on the lifting frame. The back rest is of aluminum for transparency to the radiation.

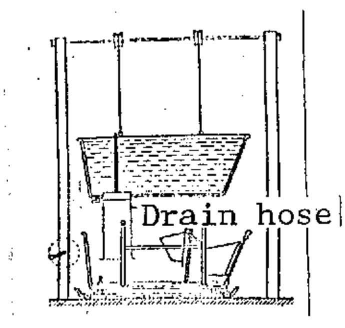


Figure 1c. Supplementary equipment: mud supply tub to make very rapid inflow of prepared mud paste possible.

thorax had to adjoin the aluminum plate so that the X-ray beam did not have to penetrate large thicknesses of water. Therefore, different fixed tilt angles were prescribed for the back wall of the tub: the steep vertical back wall (steep wall), then the slightly tilted modern standard form, and finally the extremely flat slope, called briefly the flat tub. This, to be sure, could be used only in its own framework. Anstett reports on the individual bath shapes, also in the physiological and historical respect.

2. It was also probable that bending of the body at the groin would not be completely without effect on the blood distribution and the congestion, at least for certain constitutional types. This also appeared later from quite different experiments by Korb on the effect of position on the degree of short-wave hyperthermia attainable in the lower abdomen. Therefore it was necessary to choose long bathtubs.

3. It was necessary to be able to immerse the kymograph, i. e., the device for recording the X-ray kymogram, into the water without it being damaged by the moisture. Furthermore, the kymograph had to be easily accessible for changing cassettes and yet fixed. Furthermore, it could not affect the median position of the head.

4. The entire system, containing the kymograph protected from /69
water, had to have the immersion box next to the anterior chest wall without limiting respiration.

5. It was necessary to be able to check the correctness of the adjustment by means of the fluoroscope.

The form which proved to be optimum for the realization was an aluminum immersion box with a kymograph compartment and a wide space at the front for operating the control fluoroscope screen. The side adjacent to the thorax had a thinner aluminum plate 0.5 mm thick so that it would not be necessary to accept too severe loss of X radiation. The part of the immersion box near the thorax contained the kymograph compartment proper. It had a large opening toward the foot so that cassettes could be changed quickly. The larger portion toward the foot served to accept a loosly inserted fluoroscope screen and occasionally a mirror for easier observation of the screen.

The need to support this immersion box and adjust it to the thickness of the test subject was taken into consideration by attaching pegs as feet, adjusting hollow rods at both sides, and by guide rails with clamp screws for the tile variation.

But as the experiment progressed it proved necessary to lift the test subject from the bath, in an accurately fixed position without his own activity, and to immerse him again. This was needed, for instance, to do experiments with changing bath water temperature. For this, the immersion box was combined with a seat carrier and a lifting apparatus by means of which the carrier along with the test subject and the kymograph in the immersion box could be lifted out of the tub with a winch hoist. Now for this it was necessary to apply a reinforced seat back 0.5 - 1.0 mm thick, of considerable stability, made of aluminum. On being placed in the bath, it exactly matched the aluminum back wall of the tub.

Later, it also proved convenient to provide the rear portion of the lifting rack with a tray of zinc plate at the bottom to make more comfortable sitting possible. In addition, a foot holder and a wide fixation belt were added because it appeared that shifts of the body position could occur easily on immersion into the full tub because of the buoyancy. The lifting apparatus also served so that after making the initial pictures for the experiment in the empty tub, any preparations could be undertaken in it without the test subject, as in CO_2 baths, hydrostatically heavy brine baths, etc.

As any reduction in scattered radiation would contribute to improvement of the X-ray picture quality, the radiation inlet window of the tub was later reduced to the necessary opening with a lead covering. The immersion box was covered with 0.5 mm lead foil at the side, in a water-tight envelope because of incompatibility with the bath preparation solutions.

As proved very practical, the back wall of the balneokymographic lifting apparatus was designed so that tubs could be run directly on and off on a carriage.

The height of the apparatus, 2.20 m, was determined solely by the height of the X-ray diagnostic room door. With a free choice it would have been chosen higher. More width would also have been advantageous, but this was prescribed for the same reason. Among other things, greater height would have allowed use of a higher tub carriage, which would have simplified the recording technique considerably.

On the other hand, it was more difficult to design a tub which allowed investigations with an extremely flat body position (flat tub experiment). This is the balenoroentgenkymographic flat tub apparatus (Figure 2). This design could not be realized easily because the apparatus had to be built so that the thorax would be covered with water even on its ventral side, which is the upper side here, in spite of the flat position and the low water level. This was possible only for slender types. It was /70
also necessary to set the flat tub so high that one could get the X-ray tube at the necessary distance below the tub. This

necessarily resulted in a very high apparatus.

A different and considerably more convenient solution would have been simply to put the X-ray apparatus one story lower; but this design principle could no longer be realized in 1942.

The balneoroentgenkymographic flat tub apparatus was also supposed to serve other purposes. These included investigation of the gall bladder which has not yet been started anywhere, under balneotherapeutic applications, as for observation of gall bladder function with massive hydrothermic effects, for which only the aluminum window would have had to be replaced, and investigations of the behavior of the spleen in cold and hot baths. So far, there have been only animal experiments on this.

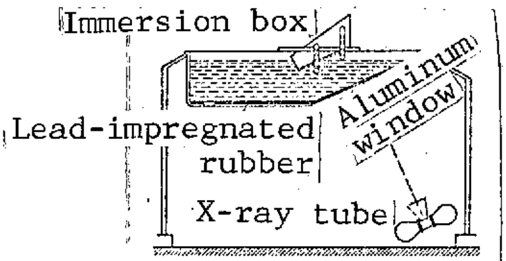


Figure 2

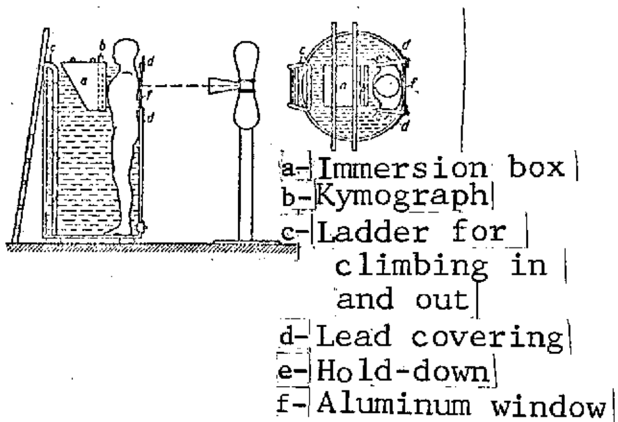


Figure 3

Figure 2. Flat tub apparatus, crudely schematized. Photographic presentation in Anstett, Balneologe 10:(1943).

Figure 3. Standing bath vessel, with the depth of a man, and with the immersion box for the kymograph. In a later design the drain opening was made considerably larger.

In order to check the conditions with significant pressure rise the device for X-ray pictures was built into a man-deep standing bath vessel (balneokymographic standing bath vessel). In primitive form, it offered no particular problems (Figure 3). Complex arrangements were necessary if rapid filling and emptying of this standing bath vessel were to be accomplished. These were investigations which we could no longer perform. They would require attachment of a water supply vessel. One of our standing bath devices was combined with a system for infrared photographs of the leg veins.

Finally, it was necessary to investigate the effect of hot and cold water alone, without simultaneous hydrostatic pressure on the body; that is, the X-ray kymographically detectable reaction to shower baths, etc. For this, it was necessary that the kymograph be completely protected from water and simultaneously to have it on a stand so that it could be tilted arbitrarily. It had to be movable, but also had to be holdable so that the reflex avoidance reaction of the test subject could not lead to a shift /71
or change of the adjustment. This goal was attained by a protective wall of Plexiglas in front of the kymograph, which was mounted on a very stable stand which could be tilted and fixed arbitrarily within the framework of the requirements (roentgenkymographic cold shower apparatus). After a test series of recordings, this apparatus was destroyed in the war.

Let us consider the reasons why the roentgenkymographic method according to Stumpf, and in particular his area kymographic form, was chosen. The investigations were done initially with X-ray pictures near the heart for general testing of the usefulness of the X-ray immersion or sunken box. Here, there appeared the inevitable disadvantages of the short-distance pictures reported for the selected X-ray kymographic method some years before. These were the severe distortion of more distant portions of the heart and the more significant size inaccuracy, a sort of masking of the pictures caused by the scattering effect of the masses of water and metal, which made the evaluation of the outlines very difficult. In addition, it was always unclear which heart phase had been recorded if one did not irradiate for a long time, accepting a certain diastolic basic form with considerably unsharpness of contour. Various switching mechanisms, as for instance, using the R peak of the ECG (described by Groedel) did not come into consideration for these studies. The method with simple heart pictures would have had only one advantage, namely, the significantly lower radiation stress on the test subject. But, as is shown later, the radiation stress in the X-ray kymographic method finally chosen varied within limits which were quite defensible and did not in any way exceed those otherwise common.

X-ray kymography, according to Stumpf allowed in addition the simultaneous evaluation, within some limits, of the so-called systolic and diastolic heart size and heart shape. The method was, then, no doubt far superior to simple heart pictures. It also yielded more contrasting images because the kymograph raster has a certain Bucky diaphragm action. Here we cannot understand systolic and diastolic strictly in the physiological sense, to be sure. As Heckmann first reported years ago from systematic experiments, there is no pure heart pulsation picture but pulsation movements summed with other heart movements (swinging movements (Heckmann, Ekert, et al.); rotation with the weather-vane shadow phenomenon of an asymmetric body with eccentric axis of rotation (Ekert); lifting motions, etc.).

Roentgen kymography, according to Stumpf, is the first practical development of the method known in principle since 1912 (Sabat), which is also much used for clinical purposes. It consists of using an X-ray-opaque metal plate with many parallel slots running across it, which is moved through a distance somewhat less than the slot separation during the X-ray exposure (some 2 - 3 seconds). To be sure, this arrangement provides only a relatively short distance for slot movement, as otherwise the fields covered by the slots, and the corresponding irradiation intensities, would overlap. Therefore one can picture only a few marginal movements of the heart if one does not wish to run the danger that because of too great compression of the movements into a very small space the peaks of marginal movement will be too greatly reduced cranio-caudally and details can no longer be evaluated, or only difficultly. But, on the other hand, one has the great advantage that, in contrast to single-slot X-ray kymography and X-ray kymography with a few slots, as reported by Sabat, Zdansky, Cignolini, and others, the whole form of the heart can be seen and evaluated. Furthermore, a synchronous comparison can be made of the motion forms of the different heart segments. This is an extraordinarily great advantage of the Stumpf method.

For the present studies, the area kymogram reproducing the heart shape without gaps was more favorable than the step kymogram in which, with otherwise identical arrangement, the film moves and the raster plate is fixed, reproducing only the movement of the heart marginal points at the separation of the slots. This would have had only the advantage that by means of the kymoscope one could have reproduced optically, although certainly rather pseudo-real, the heart motions during the kymogram exposures. / 72

Inherently, it would have been desirable from the very first to do the X-ray kymography in the full bath as a distant exposure method with 2 m distance instead of 1 m as we were forced to use. This would have reduced certain distortions of the heart shape and would have reproduced the hilus relations better, as we emphasized as early as 1939 in a presentation of our balneokymographic method.

Up to about 1950 such distant heart kymograms were not possible, as a rule, using rotating anode tubes, because these tubes would stand only voltages up to some 90 KV. The four-fold increase of radiation intensity needed from doubling of the distance, with the time limitation of the heart kymogram, can be attained only through appropriate increase in the milliamperage or the voltage. The new oil-insulated rotating anode tubes now allow voltages up to 125 KV and, thus, an approach to compensation for the required increase in intensity. If at all possible, then, people will use for balneokymographic studies apparatus and X-ray tubes which will withstand voltages up to 125 KV. With respect to usable kymograph models, we must say that the older types are better suited for balneokymography than the new ones, except for their use in standing bath equipment, where it is rather immaterial which type is used. In immersion boxes for tub baths only those models can be used which do not have too high a switch box and can be placed upside down. In this inverted arrangement a high switch box prevents the absolutely necessary raised position of the chin, which best ensures the ortho-roentgenograde position. The fluoroscopic system in the new mass-produced kymograph models cannot be used in immersion boxes because in these the raster plate must move out 40 cm to the side, and there is no room for that in the immersion box. A special arrangement with simplified switch box would be even more practical than the old mode.

The balneokymograph records the size, the shape and the marginal motion picture, or the changes in them, only at a certain state of the diaphragm.

Under the influence of hydrostatic pressure not only the state of filling and type of movement of the heart and large vessels change, as is demonstrated in our investigations; but also the type of respiration and the diaphragm movement change. Therefore it appeared desirable to establish the interplay of these factors during respiration, using X-rays, in order to clarify the applicable problems, and at the same time to record the phases lacking in the balneokymograms. It is impossible to ignore the fact that X-ray kymography never gives a total movement, but only images the components of motion in the direction of the raster slots. To be sure, one can also analyze the other components of motion by transverse and oblique positioning of the kymograph, but not simultaneously. Aside from that, one would need very large new immersion boxes and a large number of kymogram pictures. In view of the fact that indirect X-ray kymography of the heart, i. e., cinematographic recording of the X-ray fluoroscope screen picture of the moving organs with a very light-sensitive cinematographic apparatus, was so far developed in 1938 that it was possible for the thoracic organs of humans without too great X-ray stress, at /73
least for short recording times, the author, along with Willbold, designed the X-ray cinematographic immersion box device (Figure 4). A number of sample pictures were made with this device. In due time, Willbold published one sample picture from this experimental series. The device was not used for any systematic application. It later became a victim of the war.

In studies of this type, the relatively high radiation dose for the test subject was disturbing, so that such records could run only for a few seconds and the correspondingly short film strips had to be closed into an endless belt, according to Torelli.

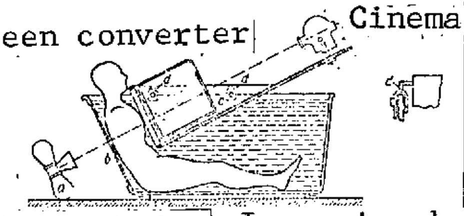


Figure 4. Equipment for X-ray cinematography. The image converter, shown as a box, represents only a possibility for continued future development and has not yet been used.

One way out of this problem might be to give up a close sequence of pictures. This is a method between serial pictures and cinematography and is often used today in serial cardio-angiography, etc.

In the meantime, the electron-optical image converter has been developed further. It amplifies the fluoroscope image by some 800 - 1000 fold, so that it gives bright fluoroscope images at very low radiation dose. It is already being used successfully in setting fractures, for X-ray cinematography of the bulbus and of movements of the appendix in humans (Janker). But, along with a certain grainy unsharpness it has the disadvantage of a relatively small image field, so that it is not suited for recording the whole thorax. It will give only partial pictures. If this disadvantage can be eliminated in continued development, combination of the X-ray cinematographic immersion box with an image converter (Figure 4) would allow us to show all the thoracic organs during breathing before and during the use of therapeutic full baths by X-ray cinematography.

2. Experimental Technique

Irradiation presented no great difficulty for the balneo-kymographic recording technique as long as we worked with kymogram pictures. It was only necessary to work with greater X-ray hardness and to irradiate more strongly.

If necessary, the studies could also be done with a half-wave machine which might be movable, in the standing bath pictures, for instance, which were restrained to another room. As a rule, though, large apparatus was used (four-rectifier and six-rectifier apparatus).

In producing such pictures, with water and metal scattering, the most careful diaphragming is necessary, partly to prevent scattered radiation from fogging the picture – there are abundant sources of scattered radiation with the experimental system required – and partly for protection of personnel (see under 3). /74

For kymogram pictures in the bath tub it is considerably more difficult to obtain a satisfactory diaphragm position. This allows an approximate comparison of the kymograms before filling the tub and with the filled tub. In particular, one must avoid breathing which would generate strong suction or pressure conditions in the thorax (Müller and Valsalva effects). As the diaphragm moves upward under the action of the hydrostatic pressure on the abdomen, the initial picture before the application of the hydrostatic pressure must in no case be made in deep inspiration. As much as possible, one makes many such initial pictures with different diaphragm positions which tend more toward the expiration position. Then, with moderate inspiration in the bath one obtains pictures which are similar, or at least approximately similar in diaphragm position, as long as a shift in the gas filling the colon does not make it entirely impossible.

In order to evaluate any changes in the thorax position one can, as appeared in the course of the work, use small pieces of fine-mesh wire netting. They can be fastened to the ventral or dorsal surface of the thorax, or both, with some Leukoplast. Wire netting is suitable because it makes it possible to detect small differences in angle. Certain unavoidable changes in the thorax shape occur, for one reason because even at 30 cm water height in a tub the size of the thorax decreases by 1 - 3 cm (Strassburger). It also changes because, as has been mentioned, the entire type of respiration and the width of the lower aperture of the thorax change.

In the man-deep standing bath the water pressure is higher and the difficulty in producing comparable diaphragm positions before and after filling is somewhat greater yet.

Kymogram pictures in the mud bath offered no more problems in X-ray technology than those in the water bath.

With respect to the circuit technology, we used hard voltages (80-90 KV with the 1936 type three-phase apparatus), and would use even higher voltages today. Such hard radiation mixtures require very careful diaphragming and extensive screening of scattered radiation, to a far greater extent than was the case in our experiments, in the interest of image contrast and of edge peak sharpness. At excessively high voltages the pictures become weak. See the next section (3) on the higher radiation danger to the personnel in use of higher voltages (hard radiation technique).

In correspondence, v. Diringshofen, who has been concerned with the problem of hydrostatic pressure in use of baths from another viewpoint, made the significant suggestion that the water height, related to the hydrostatic heart height, should always be reported in such experiments.

In the author's experience, it is important, along with the usual inquiries for broad understanding of the constitutional type of the test subject or patient, to learn something from the following viewpoints:

1. Constitutional type according to Kretschmer, Lampert and Curry

Part of this type theory refers to the wholesomeness of baths, depending on their cold or hot temperature (one could call them Sauna and Priessnitz types).

2. Determination of the balneophysiologic daily rhythm

There are types who consider only ice-cold baths in the morning, and never hot baths, as wholesome, and the converse; and in the evening they find hot or, conversely, cold baths as uncommonly beneficial. This might be related to the vegetative reaction state.

3. Establishment of the balneophysiologic degree of training in the positive or negative direction, for both temperature types /75

No doubt there is a great difference in expecting use of hot or cold, depending on whether one is dealing with an alpinist accustomed to sports or a nun, a cold fanatic or a habitue' of saunas.

4. Understanding of the vasomotor constitutional type, particularly of the collabophilic types with a constitutional tendency to orthostatic anemia of the heart, which appears even on fluoroscopy while standing and lying down.

5. Establishment of pharmacologic factors acting at the same time, such as nicotine, caffeine, etc. When there are such factors, importance should also be placed on the question of whether there is a special sensitivity in this direction.

It is certain that the degree of peripheral blood circulation is important for the residual blood volume of the heart. But the peripheral circulation is quite variably affected by the action of nicotine, caffein, alcohol, etc. There are types, from the author's experience in measurement of radiated heat, for which the sensitivity is so high that entry of a third person smoking a cigarette in the room is enough to change the heat radiated away from the body, and therefore the peripheral blood circulation, although the person without a cigarette would not affect the measurements in any way.

6. Note of any factors of the degree of abdominal filling and of the water saturation of the body (meal times, liquid intake, etc.).

7. Establishment of the psychic and somatic reaction state (vegetative dystonia, etc.).

In our experience, the peripheral vascular reaction or, inversely, the psychic reaction state, interact.

It would also be desirable to consider climatic factors and to report significant components such as the Foehn.

3. Insuring radiation protection and protection against electrical accidents in balneoroentgenologic studies

In such investigations it is very important to insure radiation protection in kymogram series, both for the test subject or patient and for the personnel. Here we deal not with single kymograms but with kymogram series which must be recorded with the same test subject, and in a milieu of water and metal masses rich in scattered radiation.

In balneokymographic investigations, the personnel are somewhat more endangered by radiation than in regular X-ray operations. In addition, most balneokymographic studies are made near the floor and, more often than other studies, require close approach to the experimental apparatus even during irradiation.

Even more, we must pay attention to radiation protection in simple X-ray cinematographic investigations; that is, those without image converters. Here the allowed dose for the test subject is reached within a few seconds and longer investigations, which is to say the recording of longer films, is not possible at all at present. For sick persons and for angiocardiography, where a vital indication is given, such as the decision about heart surgery for congenital heart problems, the conditions are more favorable, to the extent that any slight X-ray injury which might occur would be evaluated quite differently in law than would be the case with a test subject.

When an image converter is used for X-ray cinematography such investigations become practically free of danger to a considerable extent. With the image converter, for instance, it has already been possible to record bulbus movements and the function of the appendix, etc., without danger. These are much less favorable subjects than the heart.

In such experiments, 100 r in one day is considered an acceptable surface dose for a test subject or patient. Acceptable doses are higher if distributed over several days, and can be calculated approximately from Holthus' data. But after such a dose, the test subject in question should receive no other dose in the next 6 weeks without a pressing indication. Even with the pause, the 100 r cannot be repeated often arbitrarily. /76

This acceptable skin dose for a patient or a test subject has been chosen carefully. Skin reactions, such as reddening, only occur with four times that dose. Certainly it is not uncommon to reach and often even exceed the dose of 100 r when paste is adminestered. Of course, it should be noted that in this case, as a general rule, in contrast to thoracic fluoroscopy and pictures, and in contrast to kymography and X-ray cinematography, it is possible to work with a closely diaphragmed and moved radiation cone, so that a rather small radiation field moves about.

As the statements in terms of r refer to radiation absorption in cm^3, naturally the volume dose, which can be stated in r/liter, is very much greater for the same number of r and a large field of incidence than with a small entry field. But the volume dose, for which there are at present no data about an acceptable value, is decisive for the general reaction of the test subject to the X-ray effects, while the $r/^{o}$ dose contains a measure for the skin stress and the local skin reaction which might be expected. In accordance with the definition, then, there can be high volume doses even with relatively low X-ray doses having absolutely no local damage. Under some circumstances there can even be general reactions, such as radiation sickness, if the irradiated body volume is too great. We have never seen such reactions in our numerous, admittedly careful balenokymographic experiments or even in the balneocinematographic experiments, although there were only a few of them.

From our own earlier measurements referring to radiation qualities up to 90 KV, the surface dose on the back skin of the test subject reaches some 1 - 2 r per kymogram, i. e., not more than stated by Neef in 1936. This is with a total filtration of some 3.5 mm of aluminum, of which 1 mm was in front of the tube window and 2 mm was made up of the aluminum back wall or the back wall of the tub. The higher stress was compensated for, therefore, by the increased protective filtration. Theoretically, then, around 50 kymograms would have been acceptable. Because of the role of the volume dose, and because of skepticism about radiation dose measurements, which were difficult then, we never went beyond 15 kymograms under the given conditions. As a rule, we did not even reach this number. It should not be concealed that Wachsmann has recently reported many times higher radiation doses even for a simple kymogram (10-12 r). Therefore, it is best to have the incident r dose measured by a dosimetry expert before starting the experiments.

Radiation protection is considerably harder to ensure with fluoroscopy in the immersion box of the balneokymographic equipment than with kymogram series. A large extent of such fluoroscope examinations are not recommended. With the conditions which we have reported, we had to expect a dose of some 4 r/min for fluoroscopy of the heavily filtered parts in the tube, while the neck and head were totally covered.

Particularly in fluoroscopy with the balneokymograph, it must be noted that in the absence of diaphragming these neck and head parts of the test subject can receive a higher radiation dose, estimated at twice as much. This is because the tub window and the back wall of the lifting system are omitted here, acting similar to stronger aluminum protective filtering. This completely superfluous skin stress can be eliminated completely quite easily by narrowing the fluoroscopy cone by the so-called depth diaphragm, use of a suitable tube, etc., or by an additional lead plate 2 mm thick.

Anouther source of danger in fluoroscopy is that the physician or personnel can easily come into the direct radiation cone, as we are dealing with radiation near the floor, so that one can / 77
directly and unconsciously approach the X-ray tube window. This is never possible in regular fluoroscopy equipment, such as stands for lung and stomach studies. The result of this would be that the persons concerned would receive relatively high doses. Due to the increase of the dose with the square of the approach, it could amount to as much as 100 times (!) and more of the dose striking the test subject.

For all these reasons, one will use the fluoroscope only to check the proper position of the kymograph. In addition, details are often missed in fluoroscopy, and adaptation cannot be maintained in such complex experiments.

The acceptable radiation dose for the medical and paramedical personnel working with X-ray studies must not be more than 0.5 r per week according to the UVV 1953.

These limiting values are legal requirements for personnel under the Occupational Insurance for Health Service and Welfare Care, as are regular blood picture tests with respect to any radiation injury.

The radiation dose striking the assisting personnel can be determined approximately with the dental film method of Bauer and Vogler. Still better is the continuous checking of the personnel radiation dose with radiation protection plaques (Working group for radiation protection, the Medical University Clinic, Erlangen).

In such investigations we can by no means neglect protection against electrical accidents. To be sure, the author, with a number of pictures which far exceeds 1,500, has only once suffered a harmless electrical incidence at the standing bath equipment, where a ground lead had been forgotten. But one must be quite clear that use of alternating currents at 220 volts in damp rooms, and particularly in immersion boxes, where the attending personnel can easily have one hand on the kymograph housing and the other in water or on the wet test subject, is an electrical source of danger of the first order if proper safety measures are not taken. The realibility of such measures can only be evaluated in routine testing by an electrical expert, who must be made familiar with the concept and course of the studies. It is no problem in itself for such a person to reach one hundred percent safety.

4. Previous Results

The results of these investigations can be summarized in the following tables, as much as can be done without adding illustrations. Another part of the changes observed could be explained only by means of a large number of illustrations. These include, for instance, the shape changes of the kymograph peaks in detail, which occur under the hydrostatic pressure action. Individual figures have already been published (Ekert, Neumaier, Knölle, Valet, de Cillia). A systematic summary of the kymogram variants which occur with hydrostatic and thermal action on the body appears elsewhere with a large number of figures, to the extent that they are of value for the significance of the individual kymogram symptoms in the X-ray diagnostic field.

The following kymogram symptoms were observed with hydrostatic and thermal action in baths. The second and third columns indicate whether these symptoms also appear in the healthy and ill from other causes.

TABLE 1

	Occurring in the healthy without hydrostatic action	Occurring in the sick
1. Reduced movement at the lower left heart contour	Motion[+] Type II	++
2. Cessation of movement at the lower left heart contour, gaps in the movement	very rare	++
3. Cava phenomenon; i.e., widening and ventricular pulsation at the Vena cava	0	++
4. Expansion of the heart shadow in the diastolic position	0	++
5. Distortion of the heart shadow, usually more in the mitral direction	0	++
6. Strong bulging of the right atrial contour	0	++
7. Stronger pulsation of the right atrial contour	+	++
8. Cessation of movement of the right atrial contour	0	+
9. Lateral plateau development in the region of the heart apex	rare	+
10. Medial plateau development in the region of the heart apex	very rare	+
11. Systolic lateral motion in the region of the heart apex	0	+
12. Breakup of the motion in the region of the heart apex	very rare	+
13. Break in left contour	very rare	very rare
14. Brightening triangle under the lifted heart apex	rare	rare
15. Stronger changes of the character of movement or of the hilus vessels	/	+
16. Increase in the amplitude of movement of the pulmonalis arc in comparison with the behavior of the aortic bulb	0	+

	Occurring in the healthy without hydrostatic action	Occurring in the sick
17. Heart pressed to the right	0	0
18. Beveling of the lateral motion of the aortic bulb	0	+
19. Amplitude reduction in the region of the aortic bulb	0	+
20. Increased incision of the aortic medial movement	+	+
21. Changes in the size, form and position of the gastric air bubble	/	/
22. Change in the character of the drawing of the accompanying movement of the lungs	0	+
23. Reduction in size of the heart shadow	/	/

While the symptoms listed under points 1 - 8 can be understood /79 directly, the symptoms which are designated as lateral or medial plateau formation, systolic lateral movement, breakup, contour break, and beveling of the lateral motion deserve explanation. Here we are dealing with a change of the individual marginal motion peaks occurring with pulsation in the region of ventricle action. These peaks show regular hooked point forms. Now if the point of this peak is flattened off laterally, one speaks of lateral plateau formation. If the medial end of the movement is broad instead of pointed, then we speak of medial plateau formation. A systolic lateral movement is present if a lateral motion can be observed during the systole, that is, when the heart edge must move essentially to a medial position. Such a movement could occur in the heart apex region because of the upper parts of the left ventricle contracting so strongly that a compensatory lateral movement of the ventricular wall occurs in the lower portions.

But this symptom could also be related to the character of the marginal movement as an interference curve. Certainly the marginal movement is not caused only by the pulsation. Rather, as stated previously, any other movements, as a sudden motion of the heart to the left, an eccentric rotation (weathervane shadow phenomenon, etc.) add up to it. Breakup consists of a beginning of the pointed hook forms in many movements, where reflex waves may take part along with the factors mentioned. The contour break consists solely of development of an angular break in the contour of the left ventricle, perhaps due to the curvature of the lowest portion of the pericardium being somewhat flattened by its attachment to the diaphragm. The change in the movements at the aortal bulb can have a similar cause as for the ventricular movement. The beveling of the lateral movement is important here. It indicates that flow outward to the periphery is more difficult and is also observed in aortic stenosis, for instance.

The following table is particularly interesting for balneotherapy. It shows the differences in relation to the size of the heart shadow, the shape of the band of heart vessels and its type of marginal movement with the different applications. It is particularly significant that on one hand the lack of hydrostatic pressure, as in rising arm baths, foam baths, etc., reduces the number of symptoms, as does high temperature, while the CO_2 bath — and here we are dealing with an artificial one — does not in any way reduce the symptoms but rather increases them. In the therapeutic view, of course, we can draw no other conclusion than that we must also expect a stronger influence of hydrostatic pressure with these baths and migration of the blood mass toward the periphery during the application apparently does not occur. On the other hand, the absence of the tight-filling symptoms in the full bath, which is to a certain extent a removal of stress toward the periphery, is not always therapeutically important. This is shown by the full bath which, nevertheless, undoubtedly remains a stress for the circulation.

Series I and V were worked up by Blakkolb, series II by Knölle, series III by Ritter, series IV by Fink, series VI and VII by de Cillia, series VIII and IX by Valet, series XI by Anstett and series XII by Epple, and there is also an older forgotten work. The entire material was inspected and worked over in detail by Ekert and Haakh after new viewpoints and other limits had appeared in the course of the investigations. Neumaier has published kymographic studies before and after therapeutic baths. They are not contained in the following table.

This series of investigations was extensive; but it was not concluded and is not being continued because of a change in our position. A significant result of the series should be noted. This is that expansions and distortions of the heart and vascular band shadows as well as considerable changes in the heart margin movements, demonstrable by X-ray, can occur in the simple full bath and in various therapeutic full baths, at least at certain respiratory positions, specifically those covered by X-ray kymography in these studies. They can in part be considered as an expression of increased filling with blood due to the effects of the hydrostatic pressure. For many of the symptoms observed one might perhaps speak of "tight-filling symptoms". This expression anticipates nothing about the clinical and therapeutic evaluation. These symptoms do not always appear. Thus, they appear to be partly determined by constitutional and other factors. But they appear more frequently and more clearly with increase of the hydrostatic pressure; e. g., in the man-deep standing bath. / 81

TABLE 2. COMPARATIVE TABLE OF THE FREQUENT CHANGES IN THE X-RAY KYMOGRAM OF THE HEART AND THE VASCULAR BAND IN INDIFFERENT AND THERAPEUTIC TUB AND PARTIAL BATHS, ACCORDING TO WORK BY THE AUTHOR AND HIS COWORKERS, 1936-1943 /80

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
No./cases (total of 160)	16	24	7	14	8	8	14	11	20	10	16	12
Change in the heart kymogram at moderate depth of inspiration	Indifferent full tub bath, normal tub	CO_2 tub full bath, indifferent temperature	Hot full tub bath without addition	Hot foam full tub bath	Hot full tub bath with addition of extropine	Full tub mud bath, thick consistency, 41°	Full tub mud bath, thin consistency	Standing bath up to navel height, indifferent temperature	Standing bath up to collar bone height, indifferent temperature	Indifferent full tub bath in old steep tub	Indifferent full tube bath in (experimental) flat tub	Rising partial baths
1. Reduction of motion of the lower left heart contour (Transition into Type II according to Stumpf)	15:16	21:24	5:7	0	5:8	4:8	7:14	6:11	19:20	Only technically incomplete experiments; symptoms appearing somewhat stronger	11:16	0
2. Cessation of movement of the lower left heart contour, or gaps in movement at a typical position	5:16	6:24	0	0	1:8	2:8	3:14	1:11	8:20		2:16	0
3. Lateral plateau formation of the peaks in the region of the heart apex	1:16	1:24	0	0	1:8	0	0	1:11	20:20		9:16	0
4. Systolic lateral motion in the region of the heart apex	8:16	11:24	0	0	3:8	3:8	7:14	1:11	7:20		9:16	0
5. Breakup of the peaks in the region of the heart apex	5:16	10:24	3:7	1:14	2:8	2:8	5:14	1:11	10:20		9:16	0
6. Cava phenomenon; i.e., expansion and abnormal ventricular pulsation at the Vena cava superior	14:16	18:24	3:7	0	5:8	6:8	11:14	2:11	20:20		9:16 (slight)	0

(Cont'd)

TABLE 2. (Cont'd)

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
No./cases (total of 160)	16	24	7	14	8	8	14	11	20	10	16	12
Change in the heart kymogram at moderate depth of inspiration	Indifferent full tub bath, normal tub	CO_2 tub full bath, indifferent temperature	Hot full tub bath without addition	Hot foam full tub bath	Hot full tub bath with addition of extropine	Full tub mud bath, thick consistency, 41°	Full tub mud bath, thin consistency	Standing bath up to navel height, indifferent temperature	Standing bath up to collar bone height, indifferent temperature	Indifferent full tub bath in old steep tub	Indifferent full tube bath in (experimental) flat tub	Rising partial baths
7. Expansion of the heart shadow	7:16	15:24	2:7	0	2:8	2:8	7:14	8:11	18:20	Same as on preceding page	3:16	0
8. Shrinkage of the heart shadow	0	0	0	6:14	0	0	0	0	0		1:16	12:12 9:12
9. Strong deformation of the heart shadow	5:16	5:24	0	0	0	3:8	7:14	1:11	19:20		10:16	0
10. Brightening triangle under the heart apex	1:16	11:24	0	0	1:8	1:8	1:14	0	5:20		0	

The other phenomena could be observed only in isolated cases, or were only indicated by the shortness of the peak segments in the area kymograms and could not be determined numerically with certainty, as, for example, with the more frequent beveling of the lateral aortic movement.

The changes observed are not uninteresting for circulatory physiology and offer a basis for further work, even of the cardio-pharmacologic type. Under certain circumstances they also have a certain importance for practical balneotherapy, but they must first be confirmed. This could be done by making such pictures with patients before beginning a bath cure and trying to establish whether significance should be ascribed to certain water levels, manner of sitting in the tub, etc., and whether certain reaction forms react in a certain way to bath therapy. Once the equipment is provided, such studies can be performed with relatively small cost. It could well strike the understanding of patients, also, and the entire path taken would not have to be practiced in full extent with test subjects.

X-ray kymographic investigations during bath applications would be very promising; but they are still technologically difficult and, without image converters, dangerous because of radiation. Heckmann's electromyography might also be applied for more detailed analysis of the motions of certain points of the heart shadow edge, but we ourselved have no experience with it.

Summary

The author reviews the technology, the equipment required, the past results and the possibilities for future development of X-ray kymographic investigations of the central circulatory organs during the action of simple and therapeutic full baths, partial baths, and flat tub baths as well as experimental man-deep standing baths. The method determines changes in sizes of the heart and vascular band shadows, in the shape of these organs, and in their marginal movements. In part, rather considerable differences appear between the different

applications, even in respect to the size and form of the heart-vascular band shadows during the application. This is referred primarily to the different hydrostatic pressure and temperature effects and in part, perhaps, as a result of a tighter state of filling. In the author's opinion, it would probably be informative to continue these investigations using the recently reported X-ray technological equipment, perhaps even with occasional X-ray cinematographic checks. The latter, of course will be possible in large extent only after further development of electron-optical image converters. Brief reference is made to the relations of such studies, which served balneotherapeutic purposes primarily, to circulatory physiology, X-ray diagnostics, and other specialties. /82

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Translated for National Aeronautics and Space Administration under contract No. NASw 2483, by SCITRAN, P.O. Box 5456, Santa Barbara, California, 93108

STANDARD TITLE PAGE

1. Report No. NASA TT F-15,227	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle X-ray kymographic investigations of the central circulatory organs in therapeutic baths and in hydrostatic pressure elevation. Their technology, results and potential developments.		5. Report Date January 1974
		6. Performing Organization Code
7. Author(s) F. Ekert		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108		11. Contract or Grant No. NASw-2483
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of: Röntgenkymographische Untersuchungen der zentralen Kreislauforgane während therapeutischer Bäder und bei hydrostatischer Druckerhöhung. Ihre Technik, Ergebnisse und Entwicklungsmöglichkeiten

Source: Archiv. für Physikalische Therapie, Vol. 8, 1956, pp. 66-82.

16. Abstract

The author reviews X-ray kymographic investigations in therapeutic baths performed by him and his coworkers during the period 1936-1943. Findings are summarized, and suggestions are made for future work.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	35	